Report to the US Senate on E20 Ethanol Research

A. EXECUTIVE SUMMARY

Research conducted by the Rochester Institute of Technology (RIT) has focused on E20[1] fuel vehicle drivability, vehicle exhaust, and vehicle maintenance, conducted using 10 older gasoline vehicles owned and operated by Monroe County, New York State. Operation and evaluation of the test vehicles using E20 began February 19, 2008 and is on-going. To date, the vehicles have consumed nearly 5,000 gallons of E20 and have driven 75,000 miles with no fuel-related failures or significant vehicle problems. Driver comments have been strongly positive. Long-term effects of E20 usage are still being studied.

B. INTRODUCTION

Ethanol has been blended with gasoline in mixtures ranging from 0 to 97 percent. Currently, mid-level ethanol blends (E15/E20) fail to meet the EPA's "substantially similar" criteria[2] for gasoline in oxygen content (must be <=2 percent by wt, 2.7 percent for alcohol). Adoption of E20 would require a waiver under 211(f)(4) of the CAA.[3]

In the summer of 2007, the Rochester Institute of Technology (RIT) received a request from our DOT sponsor to investigate the feasibility of a limited test and evaluation of E20 ethanol in older, conventionally fueled vehicles. By partnering with Monroe County, we developed and implemented a plan to test 10 older vehicles with significant accumulated mileage (between 30,000 and 120,000 miles) on E20 to determine if there are issues that would fail to meet the "substantially similar" provision. This research was designed to take advantage of the well-documented use and historical record of the Monroe County vehicle fleet running on gasoline. The research was required to demonstrate the effects of E20 and its introduction. Vehicles chosen represent typical county fleet vehicles and consist mainly of medium and light-duty trucks, and passenger vehicles.

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[1] E20 is a mixture of 20 percent denatured alcohol and 80 percent gasoline.

[2], *Mid Level Ethanol Blend Experimental Framework – EPA Staff Recommendations*, Karl Simon EPA Office of Transportation and Air Quality, API Technology Committee Meeting, Chicago, June 4, 2008. "Substantially similar" is defined in CAA section 211(f)(4), as revised: *The Administrator, upon application of any manufacturer of any fuel or fuel additive, may waive the prohibitions established under paragraph (1) or (3) of this subsection or the limitation specified in paragraph (2) of this subsection, if he determines that the applicant has established that such fuel or fuel additive or a specified concentration thereof, and the emission products of such fuel or fuel additive or specified concentration thereof, will not cause or contribute to a failure of any emission control device or system (over the useful life of the motor vehicle, motor vehicle engine, nonroad engine or nonroad vehicle in which such device or system is used) to achieve compliance by the vehicle or engine with the emission standards with respect to which it has been certified pursuant to sections 206 and 213(a) of this title. The Administrator shall take final action to grant or deny an application submitted under this paragraph, after public notice and comment, within 270 days of the receipt of such an application.*

[3] Ibid, "Waiver Qualification."

When contemplating application of E20 fuel to the US automotive fleet, consideration must be given to E20's impact on three main areas of the vehicle system: vehicle emissions, driveability and engine fuel system durability and reliability.

The correct air/fuel ratio for combustion with E20 in vehicles designed and validated for E0–E10 applications requires 5-10 percent more E20 compared to E0-E10. Therefore, the engine management system must compensate for this change in desired air/fuel ratio by adjusting the quantity of fuel delivered during a combustion event as a function of the amount of air being introduced to the combustion chamber. In vehicles with "closed loop" compensative controls with O_2 sensor feedback in the exhaust system, the amount of delivered fuel can be adjusted within the allowable system control limits to increase or decrease the volume of fuel delivered during the combustion event, thus correcting for "lean" or "rich" operation. Two issues can arise from increasing the amount of ethanol in the fuel:

1. Lack of authority of the fuel control system to fully compensate for the increased fuel demand. This can result in setting a malfunction code within the engine and possibly operating at a lean condition. Also, initial cold start/driveability in these vehicles during start and warm up prior to "closed loop" operation may be impacted.
2. For vehicles with "open loop" engine operation, a lean combustion condition can occur when operating with E20 fuel blends. Depending on the vehicle application, this may have a detrimental effect on NOx emissions, combustion temperatures and cylinder head/seal durability as well as possible degradation in driveability. Lean startability and off-idle driveability may also be impacted.

Fuel delivery system durability may also be impacted with E20 application. The key components of the fuel system to consider are the fuel pump, fuel delivery conduits/rails and fuel injectors or carburetor in older applications. Material considerations include the impact on elastomers, polymers and metals. Relative to elastomers, increased material swell may occur in various fuel system components such as carburetor/fuel rail seals and fuel pressure regulator diaphragms and fuel hoses. This can result in failure of these components when exposed to temperature and pressure over time.

The impact of ethanol fuel blends on metal durability may also be a factor. Increased material pitting of Magnesium, Aluminum and Zinc die cast materials has been documented. Also, corrosion of steel fuel-system components may accelerate because the alcohol component of the fuel can increase the water content. This can impact internal fuel system components ranging from the fuel pump to fuel conduits/rails to injectors. Corrosion and pitting of internal components may result in fuel flow shifts, system fuel pressure loss or fuel leakage.

Deposit formation may increase with the use of E20. The higher alcohol content can increase the solubility of fuel contaminants or coatings which may later deposit on fuel injection and carburetion components such as filters and metering valves. Increased combustion chamber deposits have been noted in some trials with E20.

Another durability concern is the impact of leaner burn combustion temperatures on engine and exhaust system components. The cylinder head, head gaskets, intake/exhaust valves and exhaust catalyst may be affected by an increase in combustion temperature when using E20 blended fuels. Past studies have documented deterioration in the exhaust system catalyst caused by increased oxygen content in the exhaust.

Results obtained from our research through September 2008 are summarized in Sections C through F.

C. EMISSIONS

Emissions testing was conducted in collaboration with Delphi Powertrain Systems Technical Center in Rochester, NY. The Technical Center is a 350,000 sq-ft facility dedicated to the design, development, and testing of air/fuel systems, emission control, valve train and fuel cell systems, and components for worldwide application. The facility contains state-of-the-art testing equipment, including specialized vehicle and engine emissions equipment.

The Monroe County vehicles were tested in the lab designated as VEL2, one of the three on-site Vehicle Emissions Labs. VEL2 contains a 100 HP (75 KW) Burke Porter twin roll chassis dynamometer that can handle speed ranges of 0 to 80 MPH with road, speed and torque load modes. Data was collected through both modal engine out and tailpipe emissions for development data, or bag emissions for regulatory compliance data. The emissions analyzer was a Horiba OPE series analyzer.

The FTP-75 (Federal Test Procedure) has been used for emissions testing of light-duty vehicles for many years. The drive cycle consists of a cold start phase (505 seconds), a transient phase (864 seconds), and a hot start phase (505 seconds). The hot start phase begins after the engine is stopped for 10 minutes. The basic drive cycle parameters are 11.04 miles traveled, 1874 total seconds, with a 21.2 mph average speed. The emissions from each phase are collected in separate bags, analyzed and expressed in g/mile.

Federal FTP-75 emissions testing was conducted on each vehicle operating on regular unleaded to get baseline data and on E20. The fleet average experienced a 23.2 percent decrease in carbon monoxide (CO) emissions on E20. Nine out of 10 test vehicles experienced a reduction in CO, and all vehicles fell well within the EPA full useful life standards for the individual vehicle requirements.

The average weighted fleet tailpipe NOx decreased by 2.4 percent with five vehicles increasing NOx and five decreasing NOx. Two vehicles had increases over 25 percent; however, all vehicles were well below the EPA requirement for that vehicle.

The fleet showed a significant reduction in total hydrocarbons (THC). Nine out of 10 vehicles had a reduction in THC, with a fleet average reduction of 13.7 percent.

Federal emissions regulations do not cover the primary component of vehicle exhaust, carbon dioxide (CO_2). Fleet average CO_2 emissions were reduced by 3.6 percent, with 7 out of 10 vehicles showing a reduction.

The evaluation plan is to retest emissions starting March 2009 on E20 to determine if any degradation has occurred, and then reconvert all 10 vehicles to gasoline. This will provide additional emissions data and reveal any effects of changing fuels.

D. FUEL ECONOMY

Vehicle fuel economy theoretically declines when ethanol is blended with gasoline due to ethanol's lower energy content. More fuel is required to provide the same power, thereby increasing fuel use per mile. A fuel mileage reduction of approximately 6.5 percent can be expected if the vehicle controller is able to maintain balanced combustion conditions.

Vehicle fuel economy was calculated using the total mass of carbon-containing compounds emitted during the FTP-75 evaluation and the amount of carbon in the fuel based on the EPA carbon balance equation[4] and the measured carbon in the E20 fuel. The fleet calculated fuel economy reduced 6.8 percent from the gasoline baseline while running on E20.

"Real world" fuel economy numbers are being tracked automatically as the vehicles fill-up on E20. These numbers are compared to the fuel mileage of the same vehicles running on gasoline from previous years. Currently, the test vehicle fleet fuel mileage average for E20 is 3.5 percent higher than the same vehicles running on gasoline. This result is expected since the E20 data is only summer mileage data and the gasoline data is year-round. Historically, vehicle fuel mileage reduces during the winter; therefore, we expect the year-round E20 average fuel mileage to reduce when taking into consideration the upcoming winter mileage.

E. DRIVABILITY

The vehicle drivability and fuel economy are dramatically impacted by how a vehicle is used. The EPA lists quick acceleration, heavy braking, excessive idling, high speed driving, cold weather, and frequent short trips as some conditions that can reduce fuel economy.[5] The Monroe County test vehicles are operated by county employees and driven on public roads in a random manner based on the fleet mission. Subjective data is collected on each vehicle through review cards filled out by the driver at each refueling.

Each test vehicle is equipped with Networkcar's Networkfleet™ wireless vehicle management system.[6] This system periodically transmits vehicle location and performance information, enabling researchers to easily locate vehicles in real-time and view specific vehicle data. Networkfleet connects directly to the vehicle Engine Control Unit (ECU); therefore, it is possible to track vehicle speed, location, and instantly document any Diagnosis Trouble Codes (DTC) recorded by vehicle.

At the initiation of this program, we expected that the critical stage would be the first few "fill-ups" when the ethanol could loosen deposits in the fuel tank and lines and flush them into the filters or engine, causing adverse performance or significant engine problems. To date, these problems have not emerged.

Drivers have been issued drivability cards to record any vehicle performance issues noted during normal operation. Completed cards are turned in at every fuel fill-up. Based on subjective driver comments, the E20 vehicles seem to be running as well or better than on

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[4] 40 C.F.R § 600.113-78.
[5] http://www.fueleconomy.gov/feg/factors.shtml
[6] http://www.networkcar.com/networkcar/pub/fleet

regular gasoline. Over 300 cards have been collected and only seven minor performance changes have been noted, such as cold start difficulty and rough idling. These issues have "self-corrected" and no additional maintenance has been required.

The use of the Networkcar system has provided additional valuable insight into the internal vehicle system operation. We have received a series of so-called "pending alerts" on some of the vehicles suggesting there may be some minor adjustment issues with the new fuel. Since the alerts we received were only "pending" (intermittent or transient), they do not appear to be hard failures, rather temporary excursions outside the tolerance bands of the vehicle sensors. Most pending alerts only stated: "Engine may not be consuming fuel efficiently." These alerts may be unrelated to the E20 fuel, as one vehicle has 120,000+ miles. Our most important finding is that the malfunction (check engine) light did not illuminate on these vehicles, and drivers did not detect any performance degradation. The significance of this to consumers is that they can operate normally on E20 fuel and that their vehicles appear to adjust internally to compensate for its presence.

Vehicle performance will be quantified at the next set of emissions testing in March 2009. Horsepower and torque will be measured on each vehicle running E20 and gasoline to determine if there is a performance issue. Additional engine management parameters such as long-term trim will be collected to determine if the vehicle has enough range to compensate for the ethanol within the fuel.

F. PART DURABILITY

Maintenance on all Monroe County vehicles is recorded and electronically stored in a fleet management software database. Repair records continue to be collected and compared to the same vehicle repair records while running on gasoline. Repair records for the 10 test vehicles show no abnormal maintenance required since E20 fuel introduction. In the eight months since introducing E20, we have had no fuel or engine part failures. In the event of a failure, Monroe County technicians are instructed to set aside parts for failure analysis at RIT. At the test completion, some parts will be pulled from the vehicles and inspected.

G. CONTINUING WORK

Since we have initial positive results on E20 fuel, as a part of this evaluation, Monroe County will move their entire conventional gasoline fleet (approximately 200 vehicles) to run on E20 in November 2008. A 10,000 gallon tank is now installed at their new "Green" fueling station and is ready to receive fuel. This expansion should enable us to review the cold weather performance of a wide variety of vehicle models and manufacturers.

Argonne National Laboratory's Greenhouse gases, Regulated Emissions and Energy uses in Transportation (GREET) model version 1.8 was used to forecast the potential total life cycle emissions and energy consumption impacts for the use of E20 in the 10 gasoline vehicles provided by Monroe County. Because the ethanol being used is both produced and used in Western New York, the impacts that will be felt within the communities can be forecast in regards to emissions of both criteria air pollutants and greenhouse gases. Several parameters within the model were changed in order to capture the E20 impacts specific to the Monroe County fleet; however, many model defaults were used due to the industry-wide lack of data for E20 emissions. Generally, reductions in emissions were seen for two of the three greenhouse gases (CO_2 and CH_4) and total greenhouse gases. Criteria air pollutants and N_2O (the third greenhouse gas calculated in GREET) increased as a result of upstream stages such as corn farming, transportation and distribution as well as ethanol fuel production. We are currently modifying this model to include actual vehicle emissions collected during this evaluation.

H. CONCLUSIONS

Our research on E20 fuel vehicle drivability, vehicle exhaust, and vehicle maintenance has so far revealed no serious objections to the use of E20 in conventional vehicles. Long-term durability issues are still under study. We anticipate providing further research results by the end of 2009.